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PLASTICITY OF SENSORIMOTOR DEVELOPMENT IN THE HUMAN INFANT.

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FINDINGS WERE REPORTED ON THE ROLE OF EXPERIENCE IN THE DEVELOPMENT OF THOSE SKILLS NECESSARY FOR VISUALLY DIRECTED REACHING. THE SKILLS INVOLVED WERE THE ORIENTING, ACCOMMODATING, AND PURSUIT RESPONSES OF THE EYES, ALL OF WHICH ARE ACHIEVED DURING THE FIRST HALF-YEAR OF LIFE. SEVERAL EXPERIMENTAL CHANGES WERE MADE TO THE ENVIRONMENT OF A GROUP OF INSTITUTIONALIZED INFANTS. THESE INCLUDED INCREASED HANDLING, ENRICHED VISUAL SURROUNDINGS, AND INCREASED MOTILITY. IT WAS FOUND THAT EARLY VISUAL-MOTOR DEVELOPMENT WAS REMARKABLY PLASTIC, OR MODIFIABLE BY THE EFFECTS OF THE EVENTS EXPERIENCED. THE ONSET OF HAND REGARD AND VISUALLY DIRECTED REACHING AND THE GROWTH OF VISUAL ATTENTIVENESS WERE SIGNIFICANTLY AFFECTED BY ENVIRONMENTAL MODIFICATION. IT WAS FOUND THAT THE INFANTS WHO HAD BEEN HANDLED FOR AN ADDITIONAL 20 MINUTES EACH DAY FROM DAY 6 THROUGH DAY 36 TESTED SIGNIFICANTLY HIGHER ON VISUAL ATTENTION DURING DAYS 37 THROGH 152. THE AUTHORS CONCLUDED THAT THE AGE RANGE FROM 1 1/2 TO 5 MONTHS IS A TIME OF ENORMOUS IMPORTANCE FOR EARLY PERCEPTUAL-MOTOR DEVELOPMENT. THIS PAPER WAS COMPILED IN LARGE PART FROM AN ORAL PRESENTATION TO THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, CLEVELAND, DECEMBER 1963. IT IS PUBLISHED IN THE BOOK, "CAUSES OF BEHAVIOR--READINGS IN CHILD DEVELOPMENT AND EDUCATIONAL PSYCHOLOGY," 2ND EDITION, ALLYN AND BACON, 1966. (AL)

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9 PLASTICITY OF SENSORIMOTOR DEVELOPMENT IN THE HUMAN INFANT[1,2]/

In the Causes of Behavior: Readings in Child Development and Educational Psychology, Ed. by Judy F. Rosenblith and Wesley Allinsmith, Boston: Allyn and Bacon, Inc., 2nd ed., 1966.

BURTON L. WHITE AND RICHARD HELD

9/PLASTICITY OF SENSORIMOTOR DEVELOPMENT IN THE HUMAN INFANT[1,2]/

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INTRODUCTION

THE HUMAN INFANT ENGAGES IN countless episodes of sensorimotor exploration during the first months of life (1). Prominent among these behaviors is visually directed reaching (prehension) which is, in turn, dependent upon orienting, accommodating, and pursuit responses of the eyes. Achievement of these sensorimotor abilities occurs during the first half year of life. This paper, and the research effort of which it is a report, focuses on the role of experience in these fundamental aspects of development.

Two considerations have guided this research. On the one hand, we share with many other investigators an interest in the role of contact with the environment in the earliest development of infant behavior. On the other hand, we have been concerned with testing the implications of a specific theory of the development of sensorimotor coordination (2, 3). In testing for the contribution of early experience to development we are not prejudging the outcome of the complex issue of nature versus nurture. On the contrary, we are convinced that the endogenous mechanisms of development can best be delineated by increased understanding of the role of early contact with the environment.

The first steps in our research have been to trace the normal course of development of various fundamental sensorimotor behaviors such as reaching (1), exploratory activities (4), visual accommodation (5), and blink to approaching objects. Subsequently, we have systematically modified the rearing conditions of several groups of infants. For humane reasons the modifications must necessarily be mild. Consequently, we have required normative scales of sufficient detail and precision to reveal small changes in rates of development. Our initial studies were designed to assess the modifiability of these rates by introducing relatively gross environmental alterations. Future research, now in the planning stage, will be more analytical, with the identification of specific experiential factors as their goal.

During the daylight hours, the newborn infant is visually alert less than 3% of the time, but at six months of age this percentage is approaching 50% (6). At birth, aside from a rudimentary ocular centralizing reflex, the infant does not exhibit any ability to orient himself to visible targets. Yet, at six months, he skillfully pursues visible targets viewed at various distances and moving with a wide range of speeds. In addition, he reaches swiftly and accurately for visible objects nearby (1). At birth the infant's accommodative mechanism is incapable of tracking a visible object in depth, but at six months he is at least as adept and accurate as the normal adult (5). In these and other behaviors the six month old infant has attained a very high degree of competence. Does experience contribute to these developments? And, if so, in what ways?

Large individual differences in rates of infant development suggest that different rearing conditions have differential consequences. Hunt (7) has made this thesis explicit in his analysis of the implications of Piaget's sensorimotor theory (8). However, it has not been experimentally tested prior to the present work.

One systematic approach to the problem of the development of sensorimotor coordination derives from consideration of modifiability of function in the adult. Some of the errors induced by rearrangement of sensory inputs are com-

[1] At various stages, extending over the last six years, this research has received support from grant M-3657 from the National Institute of Mental Health, grant 61-234 from the Foundation's Fund for Research in Psychiatry, grant HD 00761 from the National Institute of Health, the Optometric Extension Program, grant NSG-496 from the National Aeronautics and Space Administration, grant AF-AFOSR 354-63 from the U.S. Air Force Office of Scientific Research, and the Rockefeller Foundation. The research was conducted at the Tewksbury Hospital, Tewksbury, Massachusetts. We are very grateful for the assistance of Mr. Peter Castle and Miss Kitty Riley and for the consideration and aid given by Drs. John Lu, Solomon J. Fleischman, Peter Wolff and Lois Crowell and head nurses Helen Efatathiou, Frances Craig and Virginia Donovan.

[2] This paper has been compiled in large part from an oral presentation to the American Association for the Advancement of Science, presented in Cleveland in December, 1963 by the senior author.

pletely compensated for after the subjects of these experiments have undergone prolonged experience in their normal environments (2, 16). Activity, initiated by the subject and performed in a dependably contoured surround, appears to be a necessary condition for full adaptation (9, 10, 11). The fact that accurate visual-motor function can be fully re-established suggests that the mechanism underlying the adaptation may also be involved in the original acquisition of such perceptual-motor skills. Confirmation of this speculation has come from experimental studies with animals (3). Kittens deprived solely of the opportunity for self-induced movements in the presence of a stable visual surround exhibited marked deficits in visual-motor development.

With infra-human species selective deprivation is a traditional tactic used for analyzing the role of experience. With human infants this procedure is inappropriate for abvious reasons. An alternative approach consists of selectively enriching the early experience of infants whose ordinary rearing conditions provide a comparatively bland psychological diet. The latter course is the one we have taken.

SUBJECTS

Our subjects were 63 infants born and reared in an institution because of inadequate family conditions. These infants were selected from a larger group after detailed evaluation of their medical histories* and those of their mothers along with relevant data on other family members whenever available. All infants included in the study were judged physically normal. Reports based on studies of institutionally-reared infants generally include a statement acknowledging atypical conditions and, in addition, such infants may congenitally constitute a non-representative sample. On the other hand, two factors make a group of such infants unusually suitable for experimental research. First, rearing conditions are virtually identical for each infant in marked contrast to the highly variable conditions for subjects reared in their own homes. Second, it is possible to systematically change rearing conditions in the institutional setting and to maintain continuous surveillance over their administration.

* Infants' daily records were screened under the supervision of Drs. P. Wolff and L. Crowell for signs of abnormality using standard medical criteria. Mothers' records were examined for possible genetic pathology and serious complications during pregnancy or delivery.

Figure 1 illustrates the typical crib setting for infants between the ages of one and four months. Clearly, the world of these infants is bland and uniform.

BASELINE DATA

Using standard test and observational procedures we have acquired the following information concerning infants reared under the regular hospital routine.

A. THE DEVELOPMENT OF VISUAL ATTENTION. In order to determine the sheer amount of visual exploratory activities exhibited by infants, and also to gain a thorough knowledge of their spontaneous visual-motor behavior, we initiated weekly 3-hour observation periods for each of our subjects.

Briefly, visual attention is defined as the state in which the infant's eyes are more than half open, their direction of gaze shifting at least once within any 30-second period.

Figure 2 illustrates the development of this activity from birth through 4 months (c. 120 days) of age. Each point represents the average of 2 scores taken during successive 2-week periods. It is interesting to note the correspond-

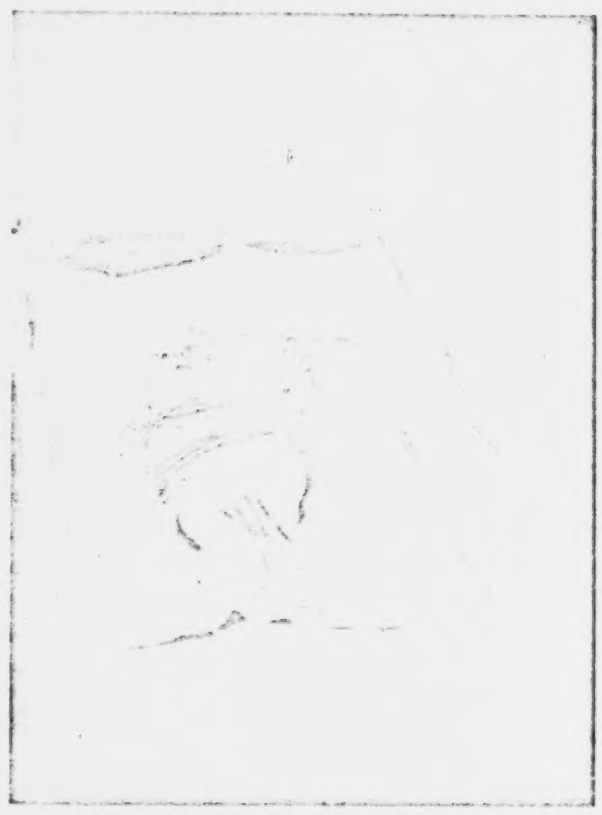

FIGURE 1.

ence between rather dramatic changes in the visible environment and the shape of this curve. For example, the sharp increase in slope at about 2 months (c. 50 days) of age occurs at about the same time as the onset of sustained hand regard (visual regard of the hands). (See arrow on Figure 2.) For the next 6 weeks or so, the child spends much of his waking time observing his fist and finger movements. The next major change in the visible environment occurred for these infants between 3½ and 4 months (c. 105-120 days, see vertical line on Figure 2). They were transferred to large open-sided cribs. The combination of greater trunk motility, enabling them to turn from side to side, and the more accessible visual surround gave them more visual experience. At about this time, the slope of the curve again shows a sharp increase.

B. THE DEVELOPMENT OF VISUAL ACCOMMODATION. Visual accommodation is the activity by which the image of a target is focused on the retina of the eye. This adjustment is largely accomplished by contraction or relaxation of the ciliary muscle which in turn changes the shape of the crystalline lens. Prior to the present research there has been no systematic study of the development of visual accommodation in human infants. We have used the technique of dynamic retinoscopy for this purpose. The test procedure is designed to measure the subject's accommodative ability under conditions more relevant to normal function than those used in traditional ophthalmological examinations. The subject's accommodation to targets placed at several distances is tested with eyes free of

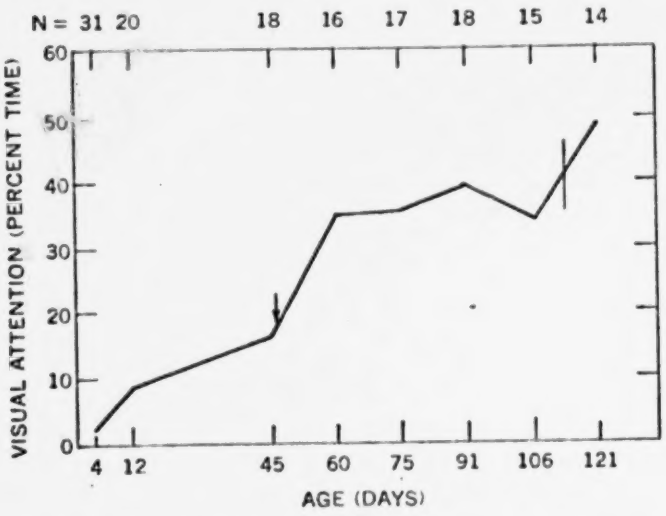

FIGURE 2 / VISUAL ATTENTION DATA–CONTROL GROUP.

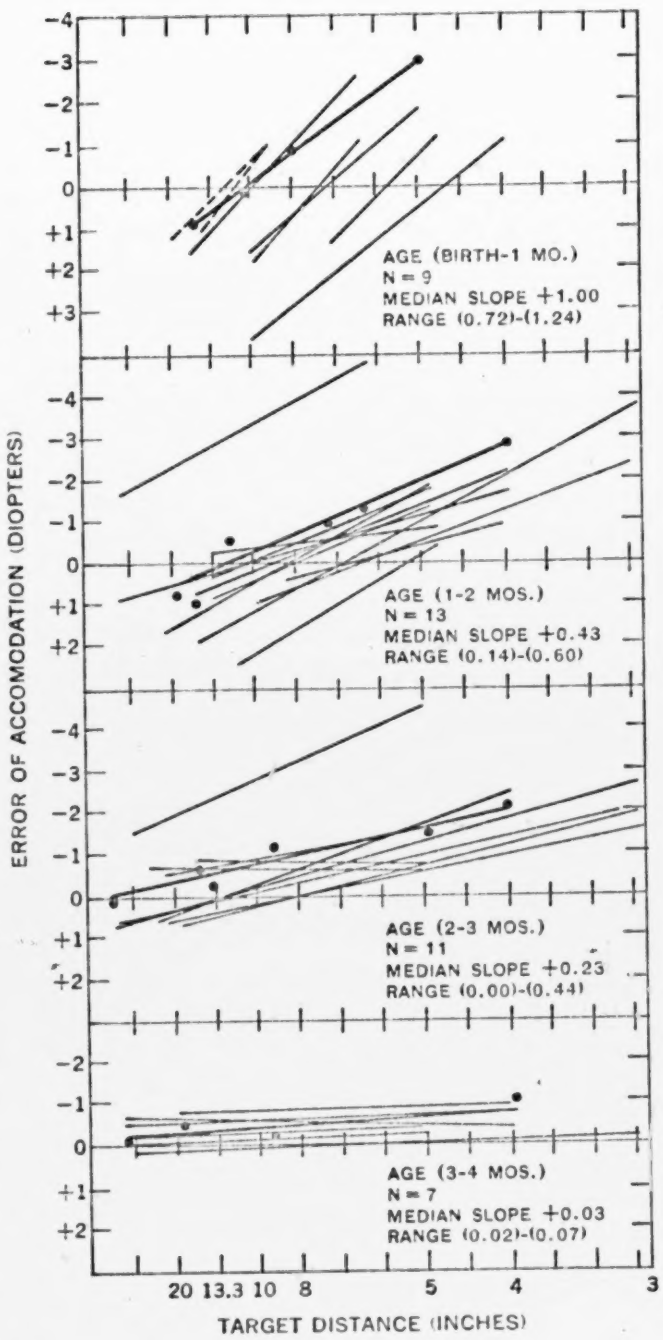

FIGURE 3* / FOUR STAGES IN THE DEVELOPMENT OF ACCOMMODATION IN THE FIRST 4 MONTHS OF LIFE. THE HEAVY LINES FITTED TO THE FILLED CIRCLES ILLUSTRATE BOTH THE PROGRESS OF A TYPICAL INFANT AND ALSO THE CLOSENESS OF FIT OF THE LINES TO THE PLOTTED POINTS. DURING THE FIRST MONTH, THE DATA THAT WERE ESTIMATED ARE REPRESENTED BY DASHED LINES. PLUS VALUES INDICATE MYOPIC PERFORMANCE. MINUS VALUES INDICATE DEVIATIONS IN THE HYPEROPIC DIRECTION.

* Reprinted by permission from Harold Haynes, Burton L. White, and Richard Held, Visual Accommodation in human infants, *Science*, 1965, *148*, 3669, 528-530.

drugs. (Routine ophthalmological examinations employ cycloplegic drugs.) He is then tested for his capacity to track the target as it is moved toward and away from his eyes. Together with Dr. Harold Haynes of Pacific University, we performed 111 dynamic retinoscopy examinations on 25 of our infants.

With the use of lenses, objective measures of accommodative performance were obtained at target distances varying from 4 to 60 inches. The infant's capacity to track the target was also tested. The instrument used was a standard Copeland streak retinoscope with a white cardboard shield mounted so as to prevent the infant from seeing the examiner's head. The results of this study are shown in Figure 3.

Perfect adjustment to changing target distance would be presented by a slope of 0.00 on the graphs (Figure 3). Complete absence of accommodative change would be indicated by a slope of + 1.00. Prior to one month of age (c. 30 days), the infant's accommodative response does not adjust to change in target distance. The system appears to be locked at one focal distance whose median value for the group is 7½ in. This is indicated by a slope value for the group of + 1.00. Occasionally, infants of this age did not remain alert long enough to allow complete calibration of their responses. In these few instances, the magnitude of error was estimated (see caption of Figure 3). Flexibility of response begins at about the middle of the second month (c. 45 days). Performance comparable to that of the normal adult is attained by the fourth month (c. 120 days), as shown by a median slope value of + 0.03.

In addition to the above measurements, eleven infants were retinoscoped while asleep in the nursery. In all eleven cases, the accommodative system was found totally relaxed. Infants less than one week of age, occasionally exhibited slow changes in accommodation, but they were in no way related to distance of the target. Older infants, when drowsy, exhibited a gradual drift of accommodation towards optical infinity suggesting that drifting seen in the first week of life is a function of level of drowsiness.

C. VISUALLY-DIRECTED REACHING. To the best of our knowledge, no previous investigator, aside

RESPONSE	OBSERVED IN	TOTAL N	MEDIAN AND RANGE OF DATES OF FIRST OCCURRENCE (DAYS) 20 40 60 80 100 120 140 160 180
SWIPES AT OBJECT	13	13	
UNILATERAL HAND RAISING	15	15	
BOTH HANDS RAISED	16	18	
ALTERNATING GLANCES (HAND AND OBJECT)	18	19	
HANDS TO MIDLINE AND CLASP	15	15	
ONE HAND RAISED WITH ALTERNATING GLANCES, OTHER HAND TO MIDLINE CLUTCHING DRESS	11	19	
TORSO ORIENTED TOWARDS OBJECT	15	18	
HANDS TO MIDLINE AND CLASP AND ORIENTED TOWARDS OBJECT	14	19	
PIAGET-TYPE REACH	12	18	
TOP LEVEL REACH	14	14	

FIGURE 4* / NORMATIVE DATA ON THE DEVELOPMENT OF VISUALLY-DIRECTED REACHING. THESE DATA WERE COMPILED BY COMBINING THE SCORES OF CONTROL AND HANDLED INFANTS (WHICH DID NOT DIFFER SIGNIFICANTLY).

* From Burton L. White, Peter Castle, and Richard Held, Observations on the development of visually-directed reaching, *Child Development*, 1964, 35, 349-364. Reprinted by permission of the Society for Research in Child Development, Inc.

from Piaget (8), has studied in detail the acquisition of visually-directed reaching. However, Piaget was not centrally concerned with prehension and he observed only three subjects. Consequently, his data, though very provocative, are primarily of suggestive value.

Figure 4 depicts the results of our normative study: a 10-step analysis culminating in visually-directed reaching (1) just prior to five months (c. 150 days) of age. Moreover, by the time swiping behavior occurs, at about 2 months (c. 60 days), the infant is prepared to focus his eyes on targets (Figure 3). Convergence of the eyes as checked by clinical procedures was also found to be effective at this time. The range of accommodation increases rapidly during the period when hand regard makes its appearance.

Hands to the midline and clasp is characteristic of the bilateral behavior seen during the fourth month (c. 120 days) of life as the influence of the tonic neck reflex drops out. Torso-orienting reflects the child's growing capacities for gross motor action. What we have called a "*Piaget-type*" *reach* was described by Piaget as a raising of one hand to the vicinity of the object, followed by alternation of glance between hand and object, a narrowing of the gap between them, and then contact. This response and the "*top level*" *reach* reflect a return to unilateral function in the fifth month (c. 150 days) of life.

We were particularly interested in the fact that swiping at objects appeared as early as the beginning of the third month (c. 70 days) whereas top level reaching did not appear until almost three months later (c. 160 days). Was this delay inevitable or a consequence of rearing conditions? Another point of interest was the question of the onset of sustained hand regard. Does this behavior presuppose a certain minimum level of acuity? What role did convergence of the eyes play here?

D. THE DEVELOPMENT OF THE BLINK RESPONSE TO AN APPROACHING VISIBLE TARGET. In Riesen's studies, young chimps deprived of experience with patterned light failed to develop the blink response to approaching visible targets (9). In Held and Hein's study of kittens deprived of self-induced motion in the presence of patterned light similar deficits developed with respect to this response (3). No such studies have been done with human infants. Even normative data on the development of this function is unavailable. The literature contains several references to the palpebral response but in each case the test circumstances combined the visual stimulus with touch or changes in air pressure as the target approached on the face.

We have performed a pilot study on 10 infants ranging in age from 1 month to 5 months of age. The apparatus we used consisted of a six inch bullseye target with ¼ in. red and white concentric rings. The object was mounted in a frame directly over the head of the supine infant. A plexiglass shield was placed 2 in. above the infant to preclude changes in air pressure as the target was dropped toward the subject. The range of target drop was from 2¾ to 12½ in. Brightness changes were not totally prevented but the sources of light were arranged to minimize such effects. Recording procedures were also crude in this preliminary effort. One observer released the target and reported the magnitude and latency of response, the other recorded the data. The results were remarkably consistent.

The median age for the onset of blinking was 2 months (c. 60 days). The maximum target drop (12½ in.) had to be used to elicit the response and it was often slow and incomplete. By 3½ months (c. 105 days), the group exhibited very rapid and complete blinks and even occasional startles in at least 7 out of 10 trials. A target drop of but 2¾ in. was sufficient to elicit these responses.

We have described baseline data for the development of four visual-motor functions, (A) visual attention, (B) visual accommodation, (C) visually-directed reaching, and (D) blinking to an approaching visible object. Are these developmental processes plastic? Is systematic contact with the environment instrumental in their development or does the infant simply grow into these skills?

EXPERIMENTAL RESULTS

A. FIRST MODIFICATIONS OF REARING CONDITIONS —HANDLING STUDY. Many recent studies have reported the remarkable effects of postnatal handling on the subsequent development of laboratory-reared animals (10, 11, 12). Mice, kittens and dogs given small amounts of extra early handling grew up to be "better" animals as measured by a wide variety of tests. They were superior in many physical and adaptive respects. Recent surveys of maternal deprivation studies by Yarrow (13) and Casler (14) suggest that early handling appears necessary for adequate human development. Sylvia Brody in her book, *Patterns of Mothering* (15), noted

that infants who received moderate handling were consistently more visually attentive than those receiving minimal handling. Would extra handling of our subjects, who normally receive minimal amounts, result in accelerated visual-motor development?

From day 6 through day 36, nurses administered 20 minutes of extra handling each day to each infant (N = 10). Measures of overall development, physical growth, general health, the development of reaching, and visual attention were taken regularly between days 37 and 152.

No changes were found in any developmental process except the growth of visual attention. The handled group was significantly more visually attentive than controls (Figure 5). Note that the shapes of the curves are quite similar. Sustained hand regard appeared about 1 week later in the handled group (day 58) than in controls (day 50). Upon relocation in large open-sided cribs the handled group, like the control group, exhibited a sharp increase in visual attentiveness.

Aside from the relationship between handling and visual attentiveness, the major finding of this study was that an environmental modification resulted in a significant alteration in the rate of growth of visual exploratory behavior. No evidence for comparable plasticity in other visual-motor developments was found following the extra handling. It is possible that further exploration of the effects of early handling would produce still greater increases in visual exploratory behavior.

B. SECOND MODIFICATION OF REARING CONDITIONS —MASSIVE ENRICHMENT STUDY. Several recent studies seem to indicate that visual-motor performance depends to a significant extent on experience of some kind for its development. Riesen's work demonstrated that chimpanzees require exposure to patterned visual stimulation for normal visual-motor development (9). His later studies have suggested that movement within a patterned environment is also required for adequate development (9). Held and his collaborators (16, 17, 18) have repeatedly demonstrated the importance of self-induced movement in dependably structured environments for adaptation to rearranged sensory inputs in human adults. More recently, their study of neonatal kittens showed the applicability of these findings to developmental processes (3). The results of this study indicated that movement *per se* in the presence of a dependable surround was insufficient for normal visual-motor development. Kittens whose movements were *externally-produced* rather than *self-induced* did not develop normally. Self-induced movement in a dependable surround was found necessary for adequate development as well as maintenance of stable visual-motor behavior.

Our subjects are normally reared under conditions which are obviously less than optimal with respect to the types of experience discussed above. Motility is limited by soft mattresses with depressions in them as well as the supine posture in which these infants are kept. The visual surround is poorly figured. Consequently, according to our hypothesis, heightened motility in an enriched surround should produce accelerated visual-motor development.

As a first test we enriched environmental contact of a group of 19 infants in as many respects as feasible.

a. Increased tactual-vestibular stimulation. Each infant received 20 minutes of extra handling each day from day 6 through day 36.

b. Increased motility. Infants were placed in the prone posture for 15 minutes after the 6AM, 10AM, and 2PM feeding each day from day 37 through day 124. At these times, the crib liners were removed, making the ward activities visible to the child. Movements of the head and trunk in the presence of a figured visual surround resulted from the normal tendency of infants to rear their heads under such circumstances. The crib mattresses were flattened, thereby facilitating head, arm, and trunk motility.

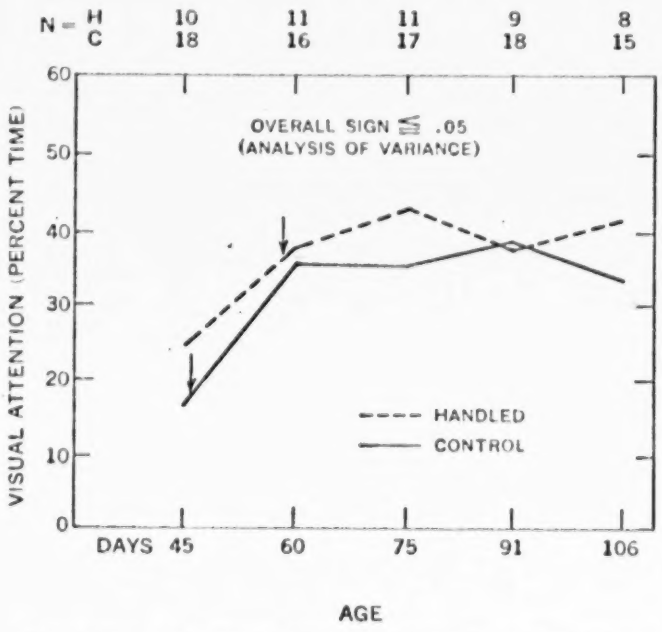

FIGURE 5 / COMPARATIVE VISUAL ATTENTION DATA.

c. Enriched visual surround. A special stabile featuring highly contrasting colors and numerous forms against a dull white background was suspended over these infants from day 37 through day 124 (see Figure 6). In addition, printed multi-colored sheets and bumpers were substituted for the standard flat white ones. These changes were designed to produce heightened visual interest and increased viewing of hand movements because of the normal tendency of infants to swipe at visible objects nearby.

Weekly measures of prehensory responses and visual attention were made. The rates of development of spontaneous behaviors related to visual-motor function such as hand regard, hands touching at the midline, mutual fingering, and torso turning were assessed from the records of the 3 hour observation periods. Performance on the Gesell tests was recorded at bi-weekly intervals to determine general developmental progress. Also, records of rate of weight gain and general health were kept.

RESULTS

1. *Hand regard and swiping*

Hand regard as such was much less frequently shown by this group as compared with controls. Instead the hands were generally first observed as they contacted portions of the experimental stabile. We called this pattern monitored stabile play and considered it together with monitored bumper play as forms of hand regard. By these criteria the onset of hand regard was delayed for some two weeks in our experimental group (N.S.–Mann-Whitney U Test). The onset of swiping was also set back, but only by some 5 days (N.S.–Mann-Whitney U Test).

Figure 7 illustrates the responses to the test object leading to reaching for this group.

FIGURE 6.

2. *Prehension*

The median age for the first appearance of top level reaching was 98 days for the experimental group, an advance of some 45 days (significant at .001–Mann-Whitney U Test). Some of the types of preliminary responses reported for our control group did not occur prior to the onset of top-level reaching.

3. *Visual attention*

The course of development of visual attention was also altered dramatically in our experimental group as illustrated by Figure 8. Concurrent with the unexpected delay in the onset of hand regard, was a marked decrease in visual exploratory behavior for the first portion of the test periods. On the other hand, once the group began to engage in prehensory contacts with the stabile and figured bumpers visual attention increased sharply.

Clearly the results of this study demonstrated the plasticity of several visual-motor developments. That the onset of hand regard is in part a function of environmental factors is not a novel notion. Hand regard is an 84th day behavior on the Gesell scale. Our control infants, with virtually nothing else to view, discovered their hands at less than 60 days of age. Piaget noted that the onset of this behavior varied by as much as three months among his own children as a function of differing environmental circumstances (8). Therefore, the fact that infants provided with enriched surrounds were late in discovering their hands as compared to controls was not totally unexpected.

We were surprised that the group exhibited less visual attention during the first five weeks in the enriched visible surround. In fact, not only did they tend to ignore the stabile and

RESPONSE	OBSERVED IN	TOTAL N	MEDIAN AND RANGE OF DATES OF FIRST OCCURRENCE (DAYS) 20 40 60 80 100 120 140 160 180
SWIPES AT OBJECT	11	14	
UNILATERAL HAND RAISING	12	13	
BOTH HANDS RAISED	12	13	
ALTERNATING GLANCES (HAND AND OBJECT)	10	11	
HANDS TO MIDLINE AND CLASP	7	10	
ONE HAND RAISED WITH ALTERNATING GLANCES, OTHER HAND TO MIDLINE CLUTCHING DRESS	5	9	
TORSO ORIENTED TOWARDS OBJECT	4	9	
HANDS TO MIDLINE AND CLASP AND ORIENTED TOWARDS OBJECT	3	9	
PIAGET-TYPE REACH	6	9	
TOP LEVEL REACH	9	9	

FIGURE 7 / THE DEVELOPMENT OF VISUALLY-DIRECTED REACHING. STUDY B–MASSIVE ENRICHMENT.

bumpers, but it is our impression that they engaged in much more crying than the control group during the same period. Starting at about 72 days of age the group as a whole began to engage in a great deal of stabile play. As we had suspected, the rattles were repeatedly swiped at thereby producing far more monitored hand and arm movements than would normally have occurred. Subsequently, in less than one month, the integration of the grasp with approach movements had been completed. Control infants had required almost 3 months for this transition.

Earlier we had noted that the course of development of visual exploratory behavior seemed to reflect the availability of interesting things to look at. We had seen that in control and handled groups the slope of the curve of visual attention increased sharply when the hands were discovered and then decreased during the next six weeks. In this experimental group it appears that for about a month starting at day 37, the enrichment was actually ineffective and perhaps even unpleasant. However, once positive responses to the surround began to occur visual attention increased sharply in striking contrast to the previous groups. At 3½ months (c. 105 days) the enriched groups exhibited much more visual activity.

C. FURTHER MODIFICATION OF THE ENVIRONMENT. Until day 37 the procedures were the same as in Study B, but instead of enrichment by prone placement and the stabile and printed sheets and bumpers, there was only one modification from day 37 until day 68. Two pacifiers were mounted on the crib rails. These devices were made to stand out visually by appending to

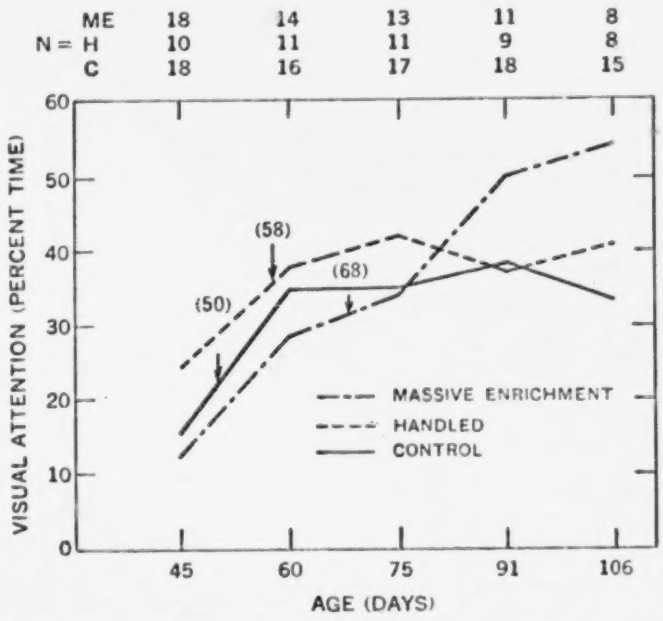

FIGURE 8 / COMPARATIVE VISUAL ATTENTION DATA.

FIGURE 9.

them a red and white pattern against a flat white background (Figure 9). The objects were 6 to 7 inches away from the corneal surfaces of the infants' eyes. They were positioned so as to elicit maximum attention from a 6 to 10 week old infant (c. 42-70 days). The normal tendency of such infants is to accommodate at about 8 to 10 inches. It was assumed that the pacifiers might have the effect of orienting the infant towards the discovery of his own hands. It was further assumed that these objects might provide appropriate anchor points in space intermediate between the locus of spontaneous fixation and the ordinary path of motion of the hand extended in the tonic neck reflex posture.

At 68 days the infant was then placed in a crib with a stabile similar to that used in the previous study until he was 124 days of age. We hypothesized that these infants would be more consistently precocious in the attainment of visually-directed reaching. We also expected consistently higher visual attention from this group.

RESPONSE		OBSERVED IN	TOTAL N
SWIPES AT OBJECT	C+H	13	13
	ME	11	14
	MOD. E	14	16
UNILATERAL HAND RAISING		15	15
		12	13
		13	16
BOTH HANDS RAISED		16	18
		12	13
		13	16
ALTERNATING GLANCES (HAND AND OBJECT)		18	19
		10	10
		12	12
HANDS TO MIDLINE AND CLASP		15	15
		17	10
		10	14
ONE HAND RAISED WITH ALTERNATING GLANCES, OTHER HAND TO MIDLINE CLUTCHING DRESS		11	19
		5	9
		7	14
TORSO ORIENTED TOWARDS OBJECT		15	18
		4	9
		5	12
HANDS TO MIDLINE AND CLASP AND ORIENTED TOWARDS OBJECT		14	19
		3	9
		4	12
PIAGET-TYPE REACH		12	18
		6	9
		8	13
TOP LEVEL REACH		14	14
		9	9
		13	13

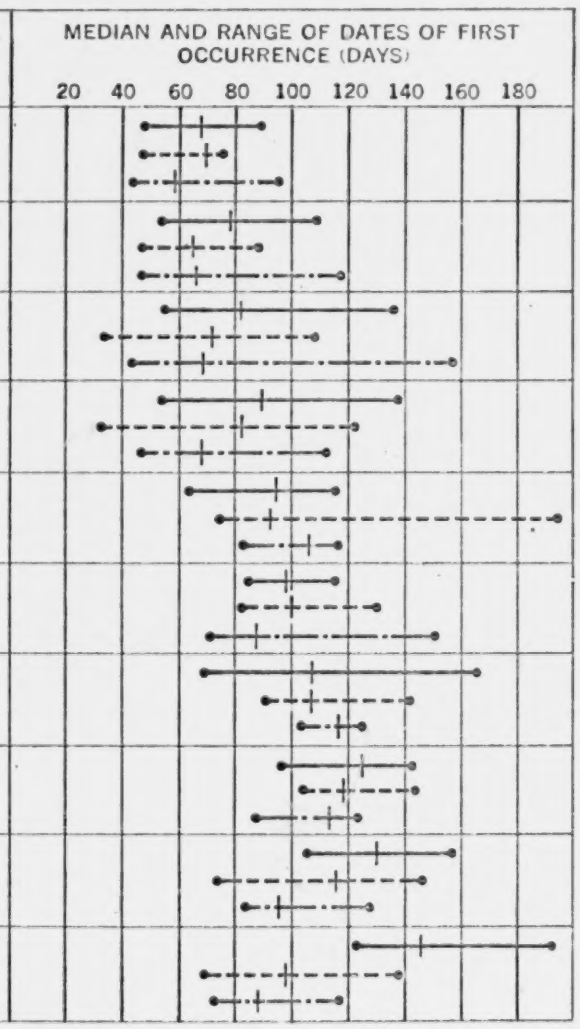
MEDIAN AND RANGE OF DATES OF FIRST OCCURRENCE (DAYS)
20 40 60 80 100 120 140 160 180
CONTROL AND HANDLED
MASSIVE ENRICHMENT
MODIFIED ENRICHMENT

FIGURE 10 / COMPARISON OF PREHENSORY RESPONSES AMONG ALL GROUPS.

RESULTS

1. *Hand regard and swiping*

In the control group the onset of sustained hand regard occurred at day 46. Infants in the handling study were slightly behind (day 58). Infants in study B were even later in this respect (day 68) supporting the idea that the discovery of the hands is, in part, a function of the availability of interesting visible objects (1). The modified enrichment of this last study seemed more appropriate for the infant during the second month of life. Study C infants exhibited sustained hand regard at day 45. It should be noted that control infants reared in bland surroundings are about as advanced in this regard. The onset of swiping responses followed the same general pattern with study C infants exhibiting this behavior earlier than all other groups (day 58: Figure 10).

2. *Prehension*

Apparently, the modified or paced enrichment of the last study was the most successful match of external circumstances to internally developing structures as indicated by the acquisition of top level reaching at less than 3 months (day 89—significantly earlier than controls at $<.001$—Mann-Whitney U Test).

3. *Visual Attention*

Figure 11 shows visual attention data for the subjects of the several studies. The depression of visual interest shown by study B infants from (day 37) to (day 74) has been eliminated. Curiously, although the last group was more consistently attentive than the others, the reduction of such behavior at 3½ months (c. 105 days) appeared as it had in the first two groups. It would appear that some uncontrolled variable is interacting with our various attempts at modifying the function.

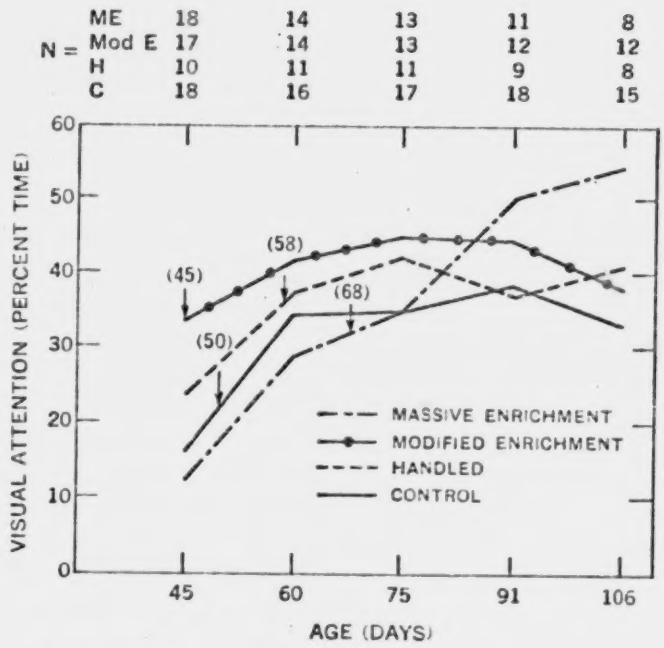

FIGURE 11 / COMPARATIVE VISUAL ATTENTION DATA.

CONCLUSIONS

1. THE SIGNIFICANCE OF THE AGE RANGE FROM 1½-5 MONTHS OF AGE. The first major conclusion derivable from our research is that the age range from 1½ to 5 months (c. days 45-150) is a time of enormous importance for early perceptual-motor development. According to our findings and those of others, human infants reared under natural conditions show a dramatic surge in both visual activity and development at the middle of the second month of life (c. 45 days). During the next 3½ months the following events occur: (1) the development of flexible accommodative function culminating in virtually adult-like performance at 3½ months (c. 105 days), (2) discovery of the hands and gradual development of manual control by the visual system culminating in true visually-directed reaching, (3) the initiation and complete development of the blink response to an approaching visible target, (4) the initiation and complete development of visual convergence, (5) the onset of social smiling.

2. PLASTICITY IN HUMAN VISUAL-MOTOR DEVELOPMENT. The studies reported above demonstrate that aspects of early visual-motor development are remarkably plastic. As yet we know neither the limits of this plasticity nor the range of visual-motor functions that fall within this classification. At the very least, the onset of hand regard and visually-directed reaching and the growth of visual attentiveness are significantly affected by environmental modification. Infants of both group B and C developed top level reaching in approximately 60% of the time required by the control group, a result very much in line with the theory that self-initiated movement with its visual consequences is crucial for visual-motor development. Whether or not visual accommodation, convergence, pursuit, and blinking to an approaching target share this plasticity remains to be seen. Assessment of the extent to

which various types of mobility and specific environmental factors contribute to these and other perceptual-motor developments is the goal of our continuing research.

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